BBC RD 1983/15

RESEARCH DEPARTMENT

REPORT

Ionospheric propagation in the l.f. broadcasting band

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THE BRITISH BROADCASTING CORPORATION November, 1983

BBC RD 1983/15
UDC 621.391.812.63:
621.3.029.4

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Summary

Continuous field-strength recordings made in the UK of l.f. transmissions from Poland and Algeria are described. The results show that sky waves propagate strongly during the day in winter, giving field strengths which are only about 15 dB less than night-time values. In winter, the transition from day to night is very gradual, with the signal strength increasing steadily for several hours. In summer, however, the daytime sky wave is very weak and the transition between day and night is more rapid.

Issued under the Authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION
November, 1983
(RA-214)

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IONOSPHERIC PROPAGATION IN THE L.F. BROADCASTING BAND

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1. Introduction

Broadcasting services in the l.f. band are liable to interference from distant co-channel transmitters when ionospheric conditions allow sky-wave signals to propagate. Although the interference occurs mainly at night, preliminary measurements made by the BBC at the end of 1975 showed that the interference could be almost as severe during winter daytime.

Interference from East European transmitters was of some concern to the BBC at that time because the UK had agreed (at the 1975 Regional Administrative Broadcasting Conference) to share two frequencies (200 and 227 kHz) with Poland. As the 227 kHz Polish transmitter was already in service, continuous field-strength recordings were made from February 1976 until March 1978. A transmission on 251 kHz from Tipasa on the Algerian coast was also measured, to enable east – west and north – south propagation over paths of similar length to be compared. The results of these measurements are described in this report.

Details of the two transmissions are given in Table 1, geographical co-ordinates being given in degrees and minutes. The Warsaw transmitter is, in fact, about 70 km west of Warsaw. The receivers were situated at the BBC Research Department at Kingswood Warren (00W13, 51N17), which is about 25 km south of London. The effective monopole radiated power (e.m.r.p.) takes into account both transmitter power and aerial gain.

Both transmissions occupied clear channels at the time of the measurements. Warsaw radiated for the whole of the measurement period but Tipasa was off the air for two months in 1977 while modifications were made to the transmitter. Warsaw radiated continuously for 24 hours a day, while Tipasa closed down for 3 hours in the middle of the day, except on Fridays.

Table 1 Transmission details

Transmitter	Warsaw	Tipasa
Longitude	19E48	2E48
Latitude	52N22	36N35
Path length, km	1380	1650
Frequency, kHz	227	251
Transmitter power, MW	2.0	1.5
E.m.r.p., dB rel 1 kW	35	33

2. Method of measurement

The receiver used initially for transmissions on 227 kHz from Warsaw had a measurement range insufficient for recording both daytime and night-time signals continuously; its gain was adjusted to record daytime field strengths only. In December 1976 this receiver was replaced by an ex-Admiralty Type B-41 receiver. This had a measurement range of 40 dB, which was adequate for continuous measurement throughout the 24 hours. The receiver input was connected to a tuned ferrite-rod aerial, and the audio-frequency output generated by its beat-frequency oscillator was rectified and fed to a pen recorder.

The 251 kHz transmissions from Tipasa were received on an Eddystone Model 850 receiver, again using a tuned ferrite-rod aerial. A sensitive pen recorder measured the a.g.c. voltage available from the receiver. The a.g.c. delay voltage was shorted-out internally in order to increase the measurement range, which then amounted to 60 dB.

Both receivers were situated in an office at Kingswood Warren where no special precautions were taken to avoid coupling with house wiring etc. Each receiver was calibrated every few days by measuring the absolute field strength on a Marconi-Ecko Type TME 18 field-strength receiver situated in another part of the building where errors caused by wiring were known in to be small. The deflection of the pen recorder at the time of this measurement was noted. The relationship between r.f. input voltage and pen-recorder deflection was then determined with the help of a Marconi Instrument Type TF 144 signal generator, thereby establishing the relationship between absolute field strength and receiver output over the full range.

3. Analysis of measurements

This section describes the analysis of the pen recordings and the conclusions which were drawn from them. The notation used to describe the variable signals (See Appendix 1) is identical to that given in Reference 1, which is a general survey of sky-wave field-strength variation.

3.1. Short-period variation

All the sky-wave signals which were observed were found to vary continuously. Variations within sample one-hour periods drawn from a whole year of recordings were studied in detail. The samples included daytime sky-waves, provided they were strong enough to be unaffected by the presence of the ground wave. Quantities determined for each one-hour period were the ratio F_s (10) between the quasi-maximum and median field strengths, the ratio F_s (90) between the median and quasi-minimum field strengths and N, the number of times the median was exceeded. These quantities varied considerably between periods but their average values are given in Table 2.

Table 2 Short-period variation

	Warsaw		Tipasa	
	Night	Day	Night	Day
F_s (10), dB	3.2	1.6	2.4	2.1
F_s (90), dB	4.9	3.0	3.4	2.7
N	5.1	2.8	4.0	1.8

The values of F_s (10) and F_s (90) are smaller than those which would be measured with a Rayleigh distribution but the night-time values of F_s (10) are similar to those which have been measured elsewhere (see Fig. 3 of Reference 1).

Fig. 4 of Reference 1 shows that a correlation exists between N and $f \cos i$, where f is the frequency and i is the angle of incidence at the ionosphere. The values of $f \cos i$ for the Warsaw and Tipasa paths are 80 and 84 kHz respectively; Fig. 4 of Reference 1 shows that the night-time values of N given in Table 2 are consistent with BBC measurements made on other paths.

Table 2 shows that the fading range and frequency is smaller during the day than at night, suggesting that the ionosphere is more stable during the daytime.

3.2. Day-to-day variation

The charts were divided into one-hour periods and the median field strength determined for each period. Thus about 30 median field strengths were obtained for each hour of the day during a month of recording*. As there was considerable variation within each group of 30 values, the median for each group was derived, together with the ratio F_D (10), between the value exceeded by three of the values (i.e. 10%) and the median for the group, and the ratio F_D (90) between the median for the group and its quasi-minimum. The values of F_D (10) and F_D (90), in decibels, were always approximately the same, indicating a symmetrical variation about the monthly median. In a few cases measurements made in the same month, at the same time, in all three years were pooled (giving about 90 values) and the distribution examined. In every case the distribution was found to be approximately log normal.

The actual values of F_D (10) were found to vary to some extent with season and time of day, as shown in Table 3.

Table 3 Day-to-day variation

Values of F_D (10), dB

	Warsaw		Tipasa	
	Night	Day	Night	Day
Winter	6.3	6.4	6.2	7.7
Spring and autumn	6.2	6.1	5.2	6.9
Summer	3.2	3.1	6.9	5.4

The values of F_D (10) for night in Table 3 are the averages of all the individual values of F_D (10) obtained for hourly periods between 22 and 02 GMT, during four-month periods defined as follows:

Winter:	November to February
Spring and autumn:	March, April, September, October
Summer:	May to August

Similarly, the daytime values are the averages for 10 to 14 GMT for the Warsaw path and 11 to 14 GMT for Tipasa.

3.3. The combined effect of short-period and day-to-day variation

Both the short-period and day-to-day variations contribute to the overall variation of the signal. Reference 1 shows that it is reasonable to assume that F (10), the amount in decibels by which the field strength exceeds the overall median for 10% of the total time at a particular time period on a series of nights (or days), is given approximately by:

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* The Friday-only mid-day transmissions from Tipasa were excluded.

$$F\,(10)^2 = F_s\,(10)^2 + F_D\,(10)^2 \qquad (1)$$

Table 4 gives values of F (10) derived from Tables 2 and 3 by means of Equation (1).

Table 4 Overall variation

Values of F (10), dB

	Warsaw		Tipasa	
	Night	Day	Night	Day
Winter	7.1	6.6	6.6	8.0
Spring and autumn	7.0	6.3	5.7	7.2
Summer	4.5	3.5	7.3	5.8

These values may be compared with those given for Band 5 (l.f.) in Sections 3 and 5 of the Annex to CCIR Recommendation 435-4, i.e. 6.5 dB at night and 5 dB for winter daytime[2]. The CCIR values were derived from the measurements described in Reference 1. The present measurements are consistent with the CCIR night-time value but the CCIR day-time value could perhaps be increased to 6.5 dB, which is the same as the night-time value.

3.4. Diurnal and seasonal variation

In the m.f. broadcasting band, sky-waves propagate with very little loss at night but are greatly attenuated during the day. The transition between day and night conditions takes place during relatively short periods at sunset and sunrise. Seasonal variations are very small by comparison and are confined mainly to changes of a few decibels in the median night-time field strength during the course of the year.

At l.f., however, diurnal and seasonal variations cannot be considered separately. For example, the transition from day to night conditions is much slower during the winter than during the summer, and significant sky-wave propagation persists during the whole of the winter day.

Fig. 1 shows the diurnal and seasonal variations observed on the Warsaw-Kingswood path. Each of the 12 sub-figures represents a particular month and is constructed from the monthly medians for each of the 24 one-hour periods into which the day is divided, as described in Section 3.2. Measurements made in different years are shown separately; there is reasonable agreement between them. Also shown are the times of sunrise and sunset; the pairs of vertical lines show that these times can vary by as much as an hour during some months. However the method of analysis used here introduces no great error at sunrise and sunset, and it does enable the variation for the entire day to be presented in a convenient form.

Fig. 1 shows that the day-time field strength is almost constant in July and August. It approximates closely to the theoretical ground-wave field strength of 49 dB (μV/m), calculated by the method described in CCIR Recommendation 368-4, assuming a ground conductivity of 10 mS/m on the land sections of the path[3]. The transitions between day and night, and vice-versa, are rapid and resemble those observed throughout the year at m.f.[1]. From September onwards the daytime field strength increases steadily, indicating the presence of a daytime sky-wave, while the transition at sunset becomes less rapid. The daytime field strength reaches its maximum value in January and February, when it is only about 10 dB below the maximum night-time value, which is not reached until about two hours before sunrise. From March onwards there is a gradual return to summer conditions.

The median field strength late at night varied between 66 dB (μV/m) and 73 dB (μV/m) during the year, with a median value of 70 dB (μV/m). This is slightly greater than the value of 68 dB (μV/m) calculated by the method described in CCIR Recommendation 435-4.

It is of interest to compare Fig. 1 with measurements[4] of the Warsaw transmission which were made at Helsinki during the years 1976-1979. Similar trends were observed, the main difference being that the ground wave was 12 dB stronger because of the shorter path length and therefore obscured the daytime sky-wave for six months of the year.

Fig. 2 shows the results of the measurements made on the Tipasa – Kingswood path. This path is longer than the Warsaw – Kingswood path and the frequency is greater; consequently the ground-wave field strength is considerably smaller and has an estimated value of about 32 dB (μV/m). Fig. 2 shows that the daytime field

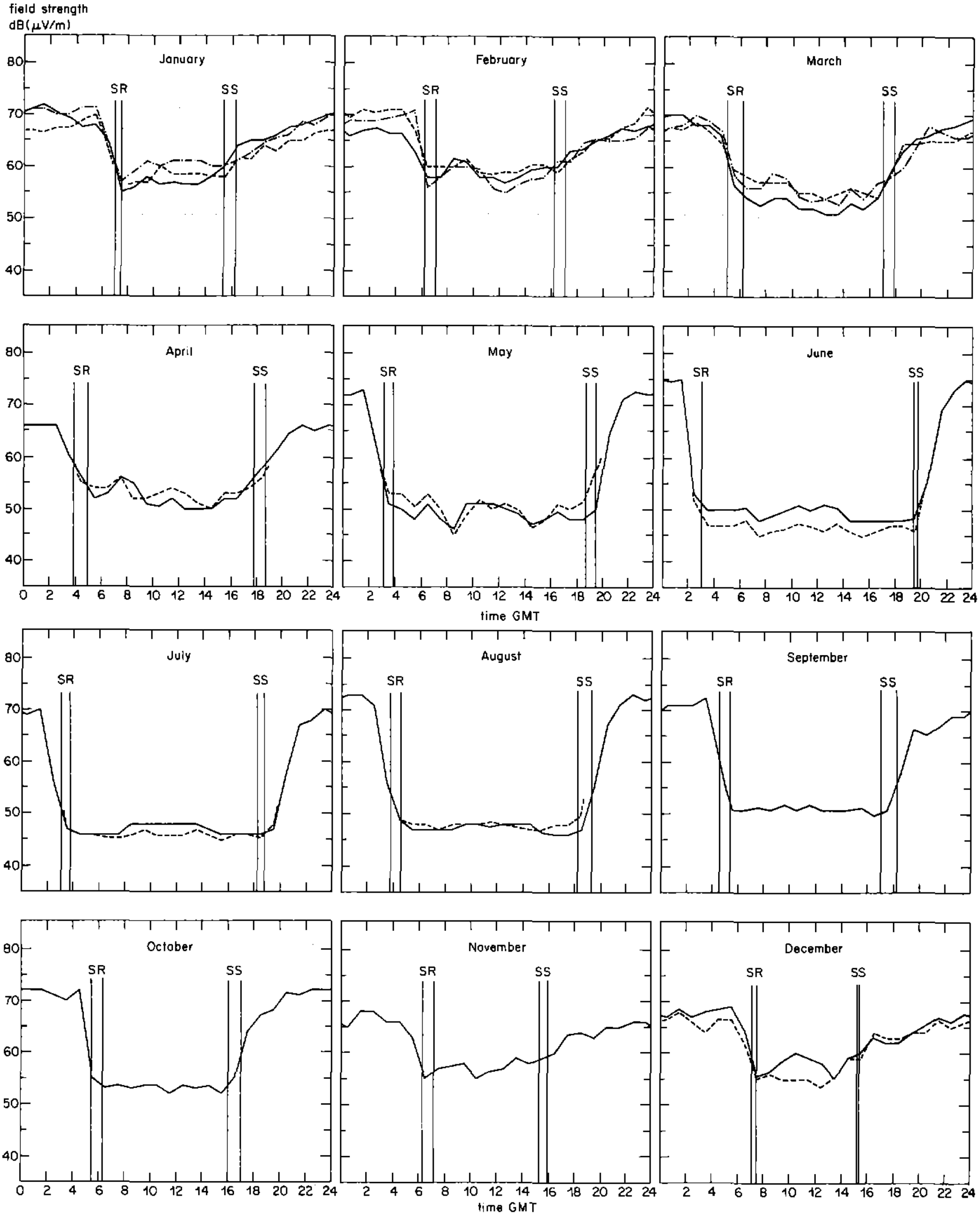

Fig. 1 – Monthly median field strengths of the Warsaw transmission measured at Kingswood.

------------ 1976 ———— 1977 –·–·–·– 1978

Frequency 227 kHz, path length 1380 km, E.M.R.P. 35 dB (kW)

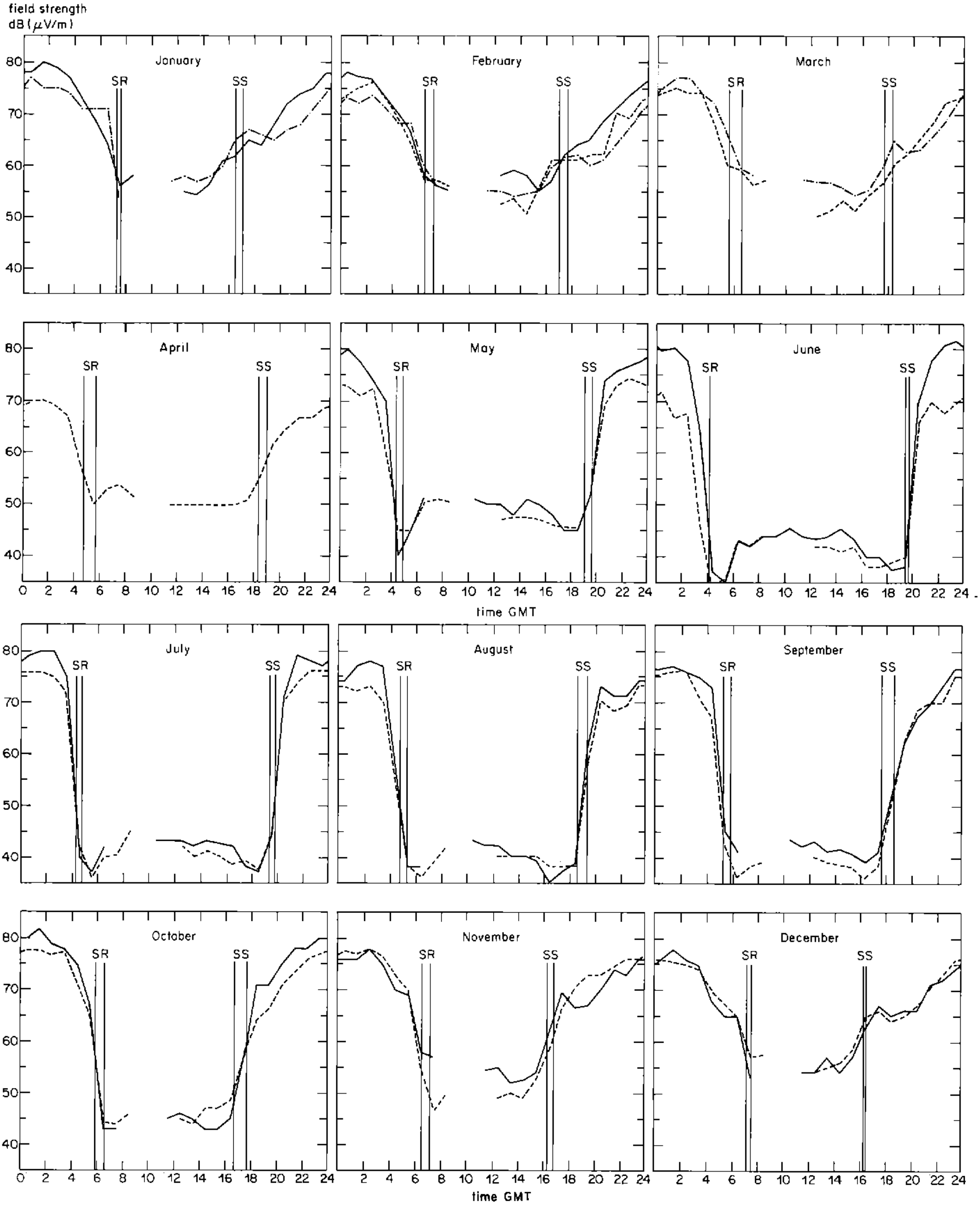

Fig. 2 — Monthly median field strengths of the Tipasa transmission measured at Kingswood.

------------ *1976* ———————— *1977* —·—·—·— *1978*

Frequency 251 kHz, path length 1650 km, E.M.R.P. 33 dB (kW) strength always exceeded this value, indicating that sky-waves were propagating even in summer. As these weak signals disappeared during the daily 3-hour period when Tipasa was off the air, there can be no doubt that they originated from that transmitter.

The diurnal and seasonal sky-wave variations show similar trends to those observed on the Warsaw – Kingswood path. In winter the slow transition between day and night conditions in the hours before and after sunset can again be seen, but the winter day-time field strength is about 20 dB less than the night-time value. The median field strength late at night varies between 70 and 82 dB (μV/m), with an annual median value of 77 dB (μV/m), which is considerably greater than the value of 69 dB (μV/m) predicted from CCIR Recommendation 435-4.

Direct comparison of Figs. 1 and 2 is permissible because both transmitters have similar effective radiated powers (see Table 1). The night-time field strength from Tipasa is about 7 dB greater than that from Warsaw despite the greater path length from Tipasa and its slightly smaller e.m.r.p. Although the Tipasa transmitter is on the coast, sea gain accounts for only about 3 dB of the difference. According the CCIR Recommendation 435-4, sky-wave field strength depends on the geomagnetic latitude of the ionospheric reflection point. However there is less than 5° difference between the geomagnetic latitudes of the mid-points of the two paths, and this is not enough to explain the difference between the two signal strengths. It is worth noting that the winter day-time field strengths on both paths are approximately the same.

4. Conclusions

The measurements described here show that sky-waves propagate at l.f. in winter during the day with an intensity which is only 10 to 20 dB less than at night. Daytime sky-waves are also observed in spring and autumn, and the evidence suggests that they continue to propagate weakly during the summer.

The transition between day and night conditions in winter is very gradual, as the field strength does not reach its maximum value until about two hours before sunrise. In summer, however, the field strength increases much more rapidly at sunset, and the diurnal variation resembles that observed at m.f.

There appears to be a significant difference between the two paths even though the geomagnetic latitudes of their mid points differ by only 5°. The night-time field strength on the Tipasa path is some 8 dB greater than that predicted by CCIR Recommendation 435-4 whereas that on the Warsaw path is only 2 dB greater than the predicted value. For both paths the winter day-time field strength is only about 10 dB less than the CCIR prediction for night time.

The short-period and day-to-day variations are similar to those measured on other l.f. paths at night but slightly greater than values previously reported for daytime.

5. References

1. KNIGHT, P. L.F. and M.F. propagation : a study of sky-wave field-strength variation. BBC Research Department Report No. 1977/12.

2. Prediction of sky-wave field strength between 150 and 1600 kHz. CCIR Recommendation 435-4, Geneva 1982.

3. Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz. CCIR Recommendation 368-4, Geneva 1982.

4. Field strength recordings of Warsaw, Poland, 227 kHz. Unpublished report by Finnish Broadcasting Authority (YLE) 1981.

6. Appendix

Notation for field stength variation.

The ionosphere is a turbulent medium and signals reflected from it are seldom steady. During an hour or less a received signal will usually exhibit several maxima and minima and will vary randomly about a median value. Median field strengths observed at the same time on a series of nights will also be found to vary randomly. These two kinds of variation are considered separately and the following notation is used to describe them quantitatively.

F_S (10)	Ratio of quasi-maximum to median field strength within a short period (dB).
F_S (90)	Ratio of median to quasi-minimum field strength within a short period (dB).
F_D (10)	Ratio of quasi-maximum of short-period medians to median value of short-period medians (dB), for short periods on a series of nights.
F_D (90)	Ratio of median value of short-period medians to quasi-minimum of short-period medians (dB), for short periods on a series of nights.
F (10)	Ratio of quasi-maximum to median field strength (dB) for the whole of the time during a series of short periods.
F (90)	Ratio of median to quasi-minimum field strength (dB) for the whole of the time during a series of short periods.

In these definitions, a 'short period' means a period of up to one hour's duration. The quasi-maxima and quasi-minima are the 10% and 90% values of the quantities being considered, respectively. Knowledge of the quasi-maximum is of importance when the effects of interfering signals are being assessed but the quasi-minimum need be known only when a sky wave is being used to provide a broadcast service.

Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP